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AUTOMATIC (TRANSFERENCE, TRANSLATION, REMITTANCE, SHUNTING)

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THE TITLE of this paper is a crude translation, such as a simple machine might prepare, of the title of a Russian paper, Автоматический Перевод. To understand why the machine translation of languages has grown to be the subject, not of science-fiction tales, but of serious scientific investigation, some understanding of the operating principles of the type of machine under consideration is essential. The first part of this paper is therefore devoted to a brief and, it is hoped, intelligible description of some important basic properties of automatic data processing machines. The attempted application of machine methods to language translation, and its consequences, is the subject of the second part of the paper. Translation from Russian to English is taken as an example throughout.

The use of automatic machines imposes on the investigator of the problems of translation a rigorously objective analytical point of view, a view of language that can be of interest to translators in general. Conversely, translation being a fine art whose origins antedate those of automatic machines by many centuries, the investigator of machine translation has much to learn from the experience of flesh-and-blood translators. Ultimately, no doubt, these two points of view will fuse into a single one from which man, relieved by automatic drudges from tedious routine manual and mental labors, can continue to apply his insight and imagination to new problems.

1. *Automatic Data Processing Machines*

The physical products of the operation of machines such as stamping presses or cigarette dispensers are of intrinsic value to their user; those of computing or translating machines, on the other hand, are valued not for themselves, but as vehicles for symbols. The tape produced by a cash register at a supermarket has little value except as a record of items purchased and of prices paid, which the housewife may use to make sure she has been charged correctly. Automatic machines of this type are now commonly called data processing machines, to distinguish them from the tools of production.

For more than a decade, automatic calculators have been used to solve with great speed and accuracy mathematical problems which heretofore could have been solved only by the expenditure of many man-lives of effort. Similar machines are replacing less automatic, less versatile machines in the bookkeeping and planning departments of commercial and industrial enterprises. There, they perform a great variety of clerical tasks requiring the transcription and filing of business data, the performance of simple calculations, and the making of routine decisions according to rules of choice which, intricate though they may be, have had to be precisely defined by the machine designer or operator.

It is, in fact, the need for precisely defined rules that makes machine translation a problem not so much of technology as of linguistics. There is only a slight oversimplification in the statement that if explicit rules for translation can be formulated, then a machine can be built to operate according to these rules. As an example of a rule which readily can be translated into machine instructions, the familiar "i before e, except after c" may be cited. There would be no difficulty in instructing a machine to check that the spelling of the words in a list is in accordance with this rule. On the other hand, to instruct a machine to choose between the alternative interpretations of the sentence "he drove here directly after work" on the basis of some characteristics of the context in which the sentence occurs would be a formidable task. The difficulties arise chiefly from the need for explicit specification of the *characteristics of the context.*

To clarify what is meant by instructing a machine to do a given job, some description of the construction and mode of operation of automatic data processing machines will be useful. One outstanding characteristic of these machines is their ability to store large quantities of data such as words or numbers in forms in which they can readily be manipulated by automatic means. In the present state of technology, these forms necessarily differ significantly from such familiar forms as ink patterns on paper or chisel marks in stone. Just as the shape and arrangement of the symbols of cuneiform script was influenced to some degree by the tools and materials available to its Assyrian users, so the materials and techniques now available have circumscribed the range of tokens usable by a machine to represent such symbols as the letters of the alphabet or the decimal numerals. Vacuum tubes are conveniently regarded as capable of assuming two states, conduction and non-conduction; a given spot on a piece of magnetic material may or may not be magnetized; a section of a card may or may not have a hole; a switch may be open or closed; a spot on a photographic plate may be opaque or transparent. The predilection for two alternatives is technological rather than logical. For example, the human eye can readily resolve many shades of gray between opaque and transparent, but the electric eye and its associated electronic circuits are tolerably reliable only when required to distinguish no more than the two extreme cases.

The available means are therefore best suited for the representation of two distinct symbols, commonly labeled *0* and *1*. It need only be demonstrated that any relevant symbol can be represented by properly arranged occurrences of *0* and *1* to establish the principle governing the storage of data in automatic machines. For example, the eight distinct composite symbols *000, 001, 010, 011, 100, 101, 110, 111* may be placed in correspondence with the letters *a, b, c, d, e, f, g, h* of the alphabet, so that *000* stands for *a, 001* for *b,* and so forth. This simple illustration is readily generalized, and should suffice to tear the veil of mystery from the notion of machine *memory:* clearly, if of three consecutive spots on a magnetic material, the first two are magnetized while the last one is not, this segment of a machine can be said to be remembering the letter *g.*

It is a relatively simple technological problem to provide a typewriter with means whereby, when its *g*-key is struck, the corresponding pattern of magnetized spots is produced in an appropriate location on the magnetic material. Conversely, such a pattern of spots can be used to control the printing of the letter *g* by a typewriter connected to the output of the machine. The user of the machine therefore need not even concern himself with the details described in the preceding paragraph. For his purposes, as distinguished from those of the technician, the memory or *data store* of a machine can be fully described in terms of customary symbols.

Storage space for letters or numbers is, in many machines, divided into bins or, as they are called, *registers,* each capable of holding a fixed number of characters. A set of characters fitting into one register is usually called a *word.* Each register is labeled with an identifying number called the *address* of the register. Some properties of a hypothetical machine having a data store with many registers will now be described. The basic instruction calls for the transfer of a word from a register *m* to another register *n*, where *m* and *n* stand for arbitrary addresses. This transfer instruction will be designated by the symbol *Tm,n,* which should be read "transfer the word in register *m* to register *n*." A series of instructions is called a *program.*

Preparing a program of instructions for a machine is hardly an automatic process. Much thought, imagination, and patient labor are required. However, once the program is complete, it can be set into the store like other data. Then the *control unit,* the nerve center of the machine, takes over. The control unit receives an instruction from storage, interprets it, and supervises its execution. Once the operation has been completed, the control unit selects the next instruction, executes it, and continues in this fashion until a stop instruction *S* is reached. Normally, if the control unit has just used an instruction obtained from register *p,* it will next select the instruction stored in register *p + 1.* Choices are made by breaking this routine, but more about this important function later.

When a word is typed on the input typewriter, it is momentarily stored in a special register associated with the typewriter, to which the address *i* (for input) may be assigned. A register *o* (for output) can store a word transferred into it from an internal register, and then control the printing of this word on the output typewriter. The instruction *Ti,n* is provided to effect a transfer from the register *i* to an internal register *n,* and the instruction *Tn,o* transfers a word from the register n to the output register *o.* The program *Ti,6 T6,9, T9,o, S* will, when obeyed, transfer a word from the input register to register *6,* copy it from *6* into 9*,* transfer it from 9 into *o,* whence it is printed. The machine then stops. Obviously, such a program has little more than illustrative value, but before more significant illustrations can be given, the repertoire of instructions must be extended somewhat.

An instruction *Cm,n* which compares the words in registers *m* and *n* will be useful. If the words in these registers are identical, the digit *1* is automatically entered into a special *choice register c,* but if the words differ in one or more letter, the digit *o* is set into the choice register. The electronic circuits which perform such tasks are somewhat complex, but it is sufficient here to take for granted that skillful engineers can construct such circuits. A companion instruction *Jn* provides for an automatic choice between alternative courses of action, according to the results of the comparison. It has already been stated that the control unit, having obeyed the instruction stored in register *25,* for example, will normally select the next instruction from register *26,* then that in register 27, and so on. If one of the instructions, say that in register *27,* is *J26,* the normal course of action may be interrupted. The instruction *J26* will, if the choice register *c* holds the digit *1*, simply be ignored, and the instruction in register *28* obeyed next. If, however, the choice register *c* holds the digit *0*, the control unit will next obey, not the instruction in register

ADDRESS OF THE REGISTER CONTAINING THE INSTRUCTION	INSTRUCTION	INTERPRETATION OF THE INSTRUCTION
25	Ti,5	TRANSFER THE WORD IN THE INPUT REGISTER TO REGISTER 5
→ 26	C5,100	COMPARE THE WORDS IN REGISTERS 5 AND 100. IF THEY ARE IDENTICAL, PLACE THE DIGIT 1 IN THE CHOICE REGISTER; OTHERWISE, PLACE THE DIGIT 0 IN THE CHOICE REGISTER.
REPLACE C5,x BY C5,x+2 REPLACE Ty,o BY Ty+2,o		
27	J26	JUMP TO THE INSTRUCTION IN REGISTER 26 IF THE CHOICE REGISTER HOLDS THE DIGIT 0; IF THE CHOICE REGISTER HOLDS THE DIGIT 1, PROCEED IN THE NORMAL FASHION.
28	T101,o	TRANSFER THE WORD IN REGISTER 101 TO THE OUTPUT REGISTER o, AND PRINT IT.
	S	STOP.

Figure 1. Dictionary Search Program

28 as it normally would, but once more that in register *26*! An example should clarify these definitions, and demonstrate the value of the instructions. A program constructed from the instructions defined thus far is given in Fig. 1. Suppose that someone has typed the Russian word перевод on the input typewriter, and that consequently this word is stored in register *i.* The first instruction transfers the word from register *i* to register 5, freeing the input register for the introduction of the next word. Next, the word is compared with that in register *100.* Then, if the two words are identical, the word in register *101,* assumed to be the English equivalent of the word in register *100,* is printed. Otherwise, the control unit once more obeys the instruction in register *26.* As indicated on the arrow in the first column of Fig. 1, the instruction *C5,100* is automatically replaced by C*5,102,* and *T101,o* is automatically replaced by *T103,o* during the transition represented by the arrow.[1] Hence the word перевод is compared with successive words stored in the machine, until the matching Russian word is found, and the proper English equivalent is printed. This simple machine is seen to be capable of functioning as an automatic dictionary.

The choice by a machine between two alternative sequences of instructions, controlled in the preceding example by a test of the identicalness of two words, can be controlled as well by a test of the validity of one or the other of any precisely defined pair of alternatives. Is a word a noun or is it not? Is its last letter *s* or is it not? Is the preceding word *of* or is it not? All of these questions, if they can be resolved by the machine, can also be used to control the choice of alternative courses of action. The resolution of the question itself is a more difficult matter. The presence or absence of the letter *s* in the last place of the word may be determined by comparing the last letter with an *s* stored in the machine. Nouns like *combination* may be identified by a similar test for the presence of the suffix *-ation,* but *day,* as contrasted to *say* or *pay,* must be identified otherwise, as by comparison with a list of nouns including *day,* and stored in the machine. The restriction to a choice among no more than two basic alternatives has its roots in considerations similar to those governing the range of basic symbols. Again, the limitation is not serious, since a choice among several alternatives can often be realized by a succession of binary choices. Figure 2 illustrates the general selection process. The first choice determines whether procedure *1* or *2,* or *3*, *4* or *5* is to be followed. If the alternatives corresponding to *yes, yes, no* are valid, the machine eventually will follow the fourth sequence of instructions.

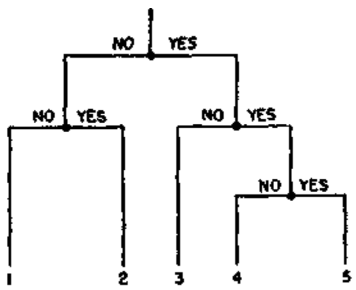

Figure 2. Selection Among Five Alternatives

While this description of machine characteristics is by no means complete — a volume would be required to do the subject justice —

the reader who imagines that the input typewriter is replaced by an automatic device, such as a tape reader, that a score or more of basic instructions are available, and that each of these instructions can be carried out by the machine in as little time as a few millionths of a second and rarely more than a few thousandths of a second, should be able to conjure up an adequate vision of an actual machine. Those wishing to plunge more deeply into the subject can turn to more specialized books.[2,3,4,5]

2. *Machine Translation*

Research in machine translation requires that all its practitioners subscribe to one common article of faith: that languages obey natural laws as stable as those governing the motions of heavenly bodies. Since the cogency of this tenet appears greater to some than to others, some explanation is in order.

To the literary mind, especially, the composition of a short story or of a poem appears as a creative act of the imagination, often prized in direct proportion to the originality of thought or diction. Originality of diction creates the more difficult problem, which will be examined presently. Original thought, however, can often be conveyed within the bounds of the most rigid rules of syntax. In fact, the very possibility of communication through a language depends essentially on the existence of lexical and syntactical conventions accepted by all speakers of the language. Communication in a language whose rules change daily is most difficult, as long recognized and exploited by cryptographers. A frequent change of rules helps to withhold the sense of vital messages from interceptors, but also burdens the legitimate receiver with the need to remember and to apply correctly a large set of rules. In spite of such efforts, however, the intrinsic regularity of languages is such that few intercepted messages remain undeciphered indefinitely. Regardless of individual variations in style or content, such characteristics of messages as the relative frequency of the letters of the alphabet and the meanings of individual words remain surprisingly constant.

The construction of every message in conventional English, say, is governed by both definite rules, and chance or willful selection. It may be considered a matter of chance that the preceding sentence contains twenty words, and it is a matter of deliberate selection that the word *English* appears in it. On the other hand, *the construction* could have been *the correct construction* but never *the writes.* When all sentences in this paper, or all papers in this book, are viewed together, these seemingly disparate influences acting on the construction of the individual sentences lead to harmonious regularity like that in the behavior of a volume of gas composed of erratically darting individual molecules. The usual distribution of English letters will be present, the word *the* will occur far more frequently than any other word, a limited number of sentence patterns will emerge, various clichés will be found.

No language, however, is a static system. As time goes on, new words are coined, others become obsolete; new technical terms become accepted household words. Yesterday's usage is archaic today, today's vivid phrase is tomorrow's cliché. The novel diction of a young writer, or the spreading influence of a new scientific discovery creates new patterns, new words. But with innovation, communication becomes more difficult. The volume of exegetic writings on the works of Joyce and of popularizations on atomic energy attest to this difficulty. The process of change and assimilation, which has led from the English of Chaucer to that of Churchill, is not yet well understood, though it is now under active study. Whatmough's theory of selective variation,[6] for example, attempts to explain the process by which yesterday's stable, intelligible pattern of a language interacts with perturbing influences to produce a new stable pattern permitting, once again, ready communication. Zipf,[7] two decades ago, observed startling regularities in data describing the relative frequency of occurrence of words and, under attack, stated "I believe that the equilibrating forces suggested by our formulae are wider and deeper than Dr. Thorndike does, and that they are acting to produce equilibrium for equilibrium's sake. Insofar as we know anything of natural processes, we see what is apparently equilibrium for equilibrium's sake everywhere." Recent work by Mandelbrot,[8] based on the mathematical theory of communication developed by Shannon[9] and others, suggests a highly plausible mathematical basis for Zipf's beliefs. Significantly, the mathematical methods employed are similar to those used in relating the regular macroscopic properties of matter to the random behavior of its microscopic constituents. Finally there are studies, like Wexler's,[10] of the linguistic turmoil attending the birth of a new terminology. There is substantial indication, in all of these works, that even linguistic change is patterned, regular. The existence of pattern in form, however, by no means precludes diversity or originality of content. The sentences *Come here!* and *Go away!*

differ in content, but are similar in form. Indeed, while certain patterns are necessarily common to all mutually intelligible writers of a language, others may be characteristic of a single writer, and serve to distinguish him from another. The statistician Yule made use of such distinctive patterns in an attempt[11] to resolve claims that Thomas à Kempis on the one hand, or Jean Gerson, on the other, is the author of *De Imitatione Christi.* Obviously, the more common patterns are of greatest interest where machine translation is concerned.

Since the metamorphosis of language is a very slow, gradual process relative to the time scale of translation, a study of the properties of contemporary language should provide most of the basic design parameters for an automatic translator. The effects of time can be accounted for by designing a machine with sufficient flexibility to permit gradual changes.

Before machine instructions for translation can be formulated, the significant patterns of both the *source* language and the *target* language must be precisely identified and put into correspondence. This requirement effectively precludes any immediate attempt at automatic translation of speech. No practical automatic devices are now available or in sight that can convert the different sound waves produced by different speakers enunciating the same word into a unique symbol for use by a translating machine. Machine translation therefore usually refers to the translation of printed texts only, where patterns are more readily recognizable. For instance, in both Russian and English, words are patterns identifiable as sequences of letters occurring between successive spaces, sentences as sequences of words between successive periods, question marks, or exclamation points.

Placing patterns into correspondence is one major linguistic problem of machine translation; devising recipes for transforming source patterns into target patterns is another. Of the existence of some solutions to these problems there is little doubt, especially for closely related languages. A unique solution seems too much to hope for. While the study of formal linguistic patterns for their own sake interests many investigators, students of information theory in particular, the formal structure of discourse is relevant to translation only as a vehicle of meaning. Corresponding patterns, therefore, must be defined as conveyors of equivalent meanings since, whatever meaning is or means, it is generally agreed that it must be preserved in translation. Consider the following passage from Turgenev's *On the Eve:*

"I would have another bathe," said Shubin, "only I'm afraid of being late.

Look at the river; it seems to beckon us. The ancient Greeks would have beheld a nymph in it. But we are not Greeks, O nymph! We are thick-skinned Scythians." [12]

In the Russian,[13] this is followed by:

—у нас есть русалки, — заметил Берсенев.

—Поди ты с своими русалками! На что мне, ваятелю, эти исчадия запуганной холодной фантазии! Эти образы, рожденные в духоте избы, во мраке зимних ночей?

which Constance Garnett[12] translates:

"We have *roussalkas"* observed Bersenyev.

"Get along with your *roussalkas!* What's the use to me — a sculptor — of those children of a cold, terror-stricken fancy, those shapes begotten in the stifling hut, in the dark of winter nights?"

C. E. Turner [14] translates:

"We, too, have our water-naiads," interrupted Bersieneff.

"Away with you and your naiads! Of what use to me, a sculptor, are these sorry offsprings of an ill-cultured northern fancy, these hideous figures born in the suffocating heat of an *isbah* [a peasant's hut], worthy types of our dark winter nights?"

Moura Budberg[1б] translates:

"We have our river-fairies," remarked Bersenev.

"River-fairies, indeed! What good are they to me, a sculptor, these figments of a cold and terror-struck imagination, conceived in the stifling atmosphere of a log-hut in the darkness of winter nights?"

And, finally, Isabel F.Hapgood[16] gives:

"We have water-nymphs also," remarked Berseneff.

"Get out with your water-nymphs! What use have I, a sculptor, for those off-spring of a confused, cold fancy, those images born in the reek of a peasant's hut, in the gloom of winter nights?"

Some of the differences between these versions are interesting. The word русалки, for which Constance Garnett merely gives a slightly altered transliteration, is given by the others as "naiads," "river-fairies," "water-nymphs." The transliteration lends a slightly exotic flavor to the passage, and acts as some unknown quantity *x,* whose value the reader must determine for himself from the context, somewhat as a native reader meeting the word for the first time might have to do. The actual translations evoke whatever ideas the reader may have associated with the words through previous reading and experience. Образы is rendered variously as “shapes,” “figures,” “figments,” “images,” and духоте as “stifling,” “suffocating heat,” “stifling atmosphere,” “reek.” In the latter case, where no single English noun corresponds exactly to the Russian, one translator abandons the formal noun to noun correspondence, two of them render the noun by a compound, viz., "духоте" = “suffocating-heat,” and one preserves the formal correspondence by taking liberties with the meaning. While the sentence structure in all four versions is acceptable English, no two sentence patterns are exactly alike, each translator hoping, by his particular choice, to approximate as closely as possible the spirit of the Russian original.

Yet, in spite of these differences, the several versions have a close kinship; their underlying meanings are clearly quite similar, although their styles, their “feels” differ. It seems then that an important aspect of meaning can be preserved over quite a range of variation in formal structure. An interesting experiment by van der Pol,[17] in which a passage was translated from English into French by one translator, the French version translated into English by another, this English version into French again and then once more into English, confirms this observation. In van der Pol’s words,

> The primary conclusion that can be drawn from this test is that the meaning has been retained to a remarkable degree, though by comparison with the original, the style of [the final English] version is entirely corrupted. Thus a person reading the original, and another reading the final text, should be able to agree on the content and the intent of the paper, although they might not be equally assisted in their appreciation of it by the respective styles.

It is thus reasonable to expect that patterns of the source language and patterns of the target language can be put into correspondence in such a way that certain kinds of meaning will be preserved, and that simple recipes for pattern transformation will emerge as well; ideally, the style of the translations obtained by the resulting process should be of a caliber comparable to the best that human translators produce. What relative roles the recipes should assign to man and machine is still an open question. Should the machine be designed to read a given text automatically, translate it, and deliver for publication a polished version untouched by human hands? Or should it perform only a part of this process and leave the remainder, as authors of mathematical texts are wont to do, “as an exercise for the reader”? The answers to these questions obviously depend on what machines can be made to do, but also on how much it costs, in research and in cash, to make them do it.

Lexical Correspondences

Two sets of elements are said to be in lexical correspondence if they are related by means of a dictionary. Thus, English *yes* is in lexical correspondence with Russian да, for, in an English-Russian dictionary, да will be found listed next to the entry *yes,* and vice versa in a Russian-English dictionary. A correspondence whereby each element of either set is associated with exactly one element of the other set, is said to be *one-to-one.* The words of one language are but rarely in one-to-one correspondence with the words of another. Opening an English-Russian dictionary to the word *rule,* one finds правило, устав, закон, линейка, etc. and conversely, under правило, one finds *rule, maxim, principle* listed. A correspondence whereby an element in one set may correspond to several in the other is labeled *one-to-many.*

It has already been demonstrated, in the first section of the paper, how an automatic machine may be programed to operate as a dictionary. The elements listed as entries in the dictionary need not be words, they may be groups of words, sentences, or even books. The recipe for finding the correspondent of an entry usually depends on juxtaposition: in an ordinary dictionary the target word is found adjacent to the listing of the source word or, in a few cases, a cross-reference index may be given. The recipe is completed by adding a prescription for the method of locating the proper dictionary entry for a given text word. In the program of Fig. 1, the dictionary entry is located by search, and the target word is assumed to be located in the register immediately following the one containing the source word. If sentences are to be listed, more capacious registers may be required, or else the program may be organized so that a group of registers each holding a word of the sentence will be treated as a unit.

In theory, automatic translation may be performed entirely by lexical means. A machine holding in storage the whole passage from Turgenev that we have quoted above, together with one of the four translations, could admirably translate that passage and any others similarly prepared. The absurdity of this procedure in practice is obvious. Lexical translation is practical only when the dictionary entries are used over and over again, as words are in different sentences and in different books. The question is simply one of mass-production; a manufacturer would be foolish to tool up an assembly line to produce one car, and equally foolish not to do so to produce a million cars.

If purely lexical automatic means cannot be used to translate books, what methods are available? An example from arithmetic will suggest the answer. Few men are capable of summing 3,563,157 and 7,201,653 at a glance, while all who have been to school can tell that 2 + 2 = 4, and many can sum larger numbers given paper, pencil, and time. The sums 2 + 2 = 4, 2 + 3 = 5, etc., and products 2 × 2=4, 2 × 3 = 6, etc., of one-digit numbers are memorized at an early stage by all school children. Obtaining the product 8 × 7, for example, is then akin to a lexical process, in which the question "8 × 7 makes . . . ?" elicits the prompt response "56." In adding pairs of larger numbers, say 256 and 137, a different process is used. The sum of 6 + 7, 13, is obtained from the "dictionary," and 3 is marked down as the first column of the sum. A unit is "carried" to the next column, and 5 + 3 = 8, then 8 + 1 = 9 are again obtained from the dictionary, and so forth. We see that using the addition table as a "small dictionary" and applying simple rules to each column in turn, is sufficient to define a process for summing any arbitrary pair of numbers. The structure of languages is so much more complex than that of simple arithmetic that an analogous process of equal simplicity is not likely to be found for translation. Nevertheless, we shall see that rules of syntax can be used to extend the power of a small dictionary, just as the rules of arithmetic extend that of the addition table. But first, let us examine lexical processes more closely.

In the early stages of research in machine translation, it occurred to many[18] that since the word dictionary plays so important a role in ordinary translation, some form of automatic dictionary most likely would be an important part of any automatic translating machine. The problems of designing an automatic dictionary have been investigated in some detail, to ascertain whether or not this basic machine itself might produce crude but useful translations, and assist in the development of more sophisticated apparatus. The results of this investigation are fully reported elsewhere;[19,20] it will suffice here to present a few salient points, beginning with some technological considerations.

The number of different words that can be stored in an automatic dictionary depends chiefly on the cost of automatic storage devices and of the circuits required to perform search operations. The larger, cheaper, and more accessible storage facilities become, the easier the theoretical problems of translation grow, since the lexical process may then be applied to the longest groups of words recurring frequently enough to preclude the absurdity of "automatic" translation of unique passages. The development of photographic storage techniques promises to yield economical means for holding thousands of source words and their target equivalents.

It has been estimated that a vocabulary of the order of 5,000 words is adequate for various limited areas of technical discourse, while estimates of the total number of words current in major Western languages range between 50,000 and 100,000. For an inflected language such as Russian the estimates must be multiplied by a factor somewhere between 5 and 10, since a noun may occur in a variety of distinct forms depending on case and number, and verb forms vary according to tense, person, and number. With a simple matching process like that of Fig. 1, an automatic dictionary can be realized only if every distinct inflected form of every word in the vocabulary is a distinct entry in the dictionary.

If the several inflected forms of a word can all be referred to one standard form listed in the dictionary, the size of the vocabulary that can be held in any given storage device is considerably greater than if space must be allocated to several variants of each vocabulary item. This is done, of course, in the ordinary dictionary; the dictionary user must then rely on his knowledge of the rules of the language to associate word forms as they occur in texts with the standard forms listed in the dictionary. The process of association is so simple, so unconscious for a person familiar with a language, that the complexity of equivalent automatic processes is somewhat startling.

Various processes have been suggested for automatic reduction to standard form; For languages where inflected forms are created by adding different suffixes to a common stem, most writers[21,22] propose to match the word as it occurs in the text with dictionary entries. If an entry identical to the word is found, the process terminates. Otherwise, some letter of the word is deleted, and the matching process repeated. The alternation of matching and deletion continues until either the remainder of the word is found to be identical to a stem listed in the dictionary, or the number of deleted letters exceeds some fixed limit. A number of practical difficulties arise in this process but none are so serious as the fact that the repeated matching process can grow very time-consuming or costly even in a millisecond time scale.

A method has been developed for isolating inflectional affixes directly, without recourse to a matching and deleting process. The

можем	довольно	элементарных
решением	по	многополюсных
выберем	то	контактных
схем	место	эквивалентных
причем	что	аналогичных
запишем	это	обычных
дальнейшем	например	наконец
другим	с	матриц
таким	класс	бы
одним	принадлежат	способы
заметим	аппарат	чтобы
обозначим	бывает	мы
следующим	дает	схемы
рядом	возникает	суммы
образом	будет	равны
полюсником	имеет	законы
целом	следует	пары
самом	характеризует	алгебры
известном	представляет	элементы
матричном	элемент	работы
обычном	от	единицы
некотором	будут	матрицы
этом	замкнут	цепь
успехом	дают	использовалось
двум	отсутствуют	рассматривать
величин	образуют	использовать
о	стоят	называть
множество	между	записывать
общего	синтезу	задать
такого	анализу	обладать
булевского	характеристику	указать
заданного	схему	обозначать
последовательного	одному	изучать
некоторого	тому	получать
этого	поэтому	иметь
несколько	алгебру	предложить
только	классу	положить
число	полюсу	определить
но	работу	заменить
одно	матрицу	получить
можно	матрицах	часть
возможно	всех	есть
релейно	булевских	проводимость
естественно	электрических	возможность
недостаточно	этих	пусть
параллельно	идущих	речь
желательно	слагаемых	лишь
относительно	всевозможных	операцию
значительно	составленных	собою
равносильно	полученных	каждую

Figure 3. End-Alphabetized Words

technique of alphabetizing words according to their terminal letters, rather than, as usually, according to their initial letters, has proved invaluable in the development of this method and in other aspects of the study. Figure 3 is a list of a few end-alphabetized Russian words, on which suffix patterns are discernible. When longer lists are used, as they were in practice, these patterns appear in bold relief, and help in devising rules for separating affixes. These rules take the form of statements such as "If the last letter of the word is у and the penultimate letter is not м, or, if the penultimate letter is м but the third letter from the end is neither е nor о, then the suffix is у." Such statements could be converted into programs for effecting a series of decisions, as in Fig. 2. It is also possible to devise simple circuits that will isolate suffixes according to these rules in approximately the time required for a machine to execute a single instruction, and this is the important advantage of the method. By whatever means inflectional suffixes are separated, not only is a reduction in word storage capacity achieved, but the suffixes themselves are of potential value in the implementation of syntactical rules.

The reader who has tried to apply the rule given in the preceding paragraph to those words in Fig. 3 ending in -у, may have discovered that the rule permits the separation of у from между, which is indeclinable. So long as the remaining stem, in this case межд-, uniquely identifies the word, nothing is lost. Indeed, such cases may be turned to advantage, as an examination of Fig. 4 will reveal. A number of stems, obtained from words in running text according to rules of the type described above, are listed in Fig. 4 in end-alphabetic order. Since the sample, from which this list was prepared is larger than that used for Fig. 3, the terminal letter patterns are quite striking. It is clear that the recurrent terminal letters in no way contribute to the identification of the words in which they occur, and hence could be deleted without impairing word identification. If storage space were at a premium, the consequent reduction in storage requirements would be valuable. Some other variations of this approach have been described by Bull, Africa, and Teichroew.[28] Considerations of storage may not prove compelling enough in themselves to warrant the implementation of these ideas, but a further inducement might. Most of the terminal letter patterns of Fig. 4 are characteristic of nouns. Thus, -ени identifies a common class of abstract nouns, most stems in -аци appear in cognates of English nouns in *-ation.* This suggests that storing only the distinctive parts of all stems having a com-

нарастани	выделени	сообщени
возрастани	усилени	помещени
испытани	оформлени	допущени
затухани	накоплени	лини
вещани	замени	удлини
радиовещани	измени	выполни
сравни	примени	напомни
возникновени	распространени	влияни
проникновени	устранени	состояни
соприкосновени	сравнени	строи
падени	уравнени	поступи
совпадени	усреднени	измери
введени	затруднени	критери
воспроизведени	изменени	теори
прохождени	применени	при
подтверждени	соединени	радиопри
возбуждени	дополнени	тригонометри
телевидени	выполнени	эмисси
наблюдени	выяснени	нажати
искажени	строени	обрати
изображени	измерени	замети
отражени	повторени	отмети
выражени	рассмотрени	развити
движени	оцени	приняти
снижени	значени	поняти
продолжени	назначени	реализаци
наложени	послесвечени	сигнализаци
разложени	обеспечени	организаци
приложени	течени	электризаци
положени	истечени	генераци
предположени	увеличени	операци
сложени	ограничени	регистраци
умножени	укорочени	компенсаци
сужени	изучени	флуктуаци
напряжени	получени	экспозици
биени	заключени	функци
ослаблени	включени	самоиндукци
приспособлени	подключени	станци
давлени	решени	радиостанци
направлени	отношени	корреляци
управлени	соотношени	изоляци
сопротиблени	нарушени	модуляци
установлени	улучшени	манипуляци
осуществлени	повышени	обозначи
явлени	уменьшени	обеспечи
появлени	вращени	наличи
проявлени	возвращени	отличи
делени	приращени	ограничи
определени	прекращени	получи
распределени	сокращени	наруши

Figure 4. End-Alphabetized Stems

mon terminal letter pattern in a common section of the store identified by the letter pattern would not only eliminate the need to store redundant letters, but would also suffice to identify the part of speech of the corresponding words. This identification, like that of inflectional suffixes, can be of value in the implementation of syntactical rules.

Frequent one-to-many correspondences between Russian and English words create, as might be expected, one of the most perplexing problems of automatic translation. Since most methods yet proposed for automatic selection among multiple correspondents depend on the application of syntactical rules, their consideration will be deferred. Purely lexical methods are few: the selection may be left to the reader, as it is when ordinary dictionaries are used; it may be made when the dictionary is compiled, as in the making of specialized technical dictionaries; or, a variant of the latter, alternative correspondents may be tagged as relevant to specialized fields of knowledge, and selected according to a field identification accompanying the text to be translated, again a common procedure with ordinary dictionaries.

The selection of correspondents when the dictionary is compiled is susceptible to bias in favor of the selection of those correspondents that best fit a few test sentences to be translated. The results of some highly publicized machine translation experiments[24] are questionable on this and similar counts. This method can be trusted only if many texts, preferably unpublished at the time of selection, can be processed satisfactorily with such a dictionary. Nevertheless, this method, or its variant, eventually may prove to be the only one practicable for most words.

Some limited experiments have been conducted with procedures which an automatic dictionary without selected correspondents could carry out.[19] These procedures too remain to be tested on a large scale, and preparations for such a test are under way. For the limited experiment, the Russian words in a sample text were assigned the correspondents given in a standard Russian-English dictionary. The title of the present paper is typical of the results. The words within parentheses are the English correspondents of the Russian word перевод. Since автоматический corresponds to *automatic* in one-to-one fashion, grouping within parentheses is not necessary.

Is it justifiable to call the product of such an automatic dictionary a translation? The experimental results suggest that for scientific texts the answer is yes. A monolingual reader, expert in the subject matter of the text being translated, should find it possible, in most instances, to extract the essential content of the original from this crude translation, often more accurately than a bilingual layman. He is helped by the fact that Russian word order, in scientific writing at least, is very close to that of English. The absence of number, case, and tense information is no major hindrance, but the great multiplicity of alternatives within parentheses is confusing, and, as the strongest roadblock on the way to comprehension, is responsible for most of the delay in attaining this goal. The simple expedient of ranking alternative correspondents in order of frequency, and printing the most frequent in bold letters, might help matters considerably. The reader, taking the boldly printed words as the translation, could read the text with less confusion than with uniformly presented alternatives, but could, in doubtful cases, examine the other alternatives more closely.

There is every indication that an automatic word dictionary would be a valuable tool. Even in cases where a text as translated by such a dictionary is not wholly intelligible, it is possible at least to decide whether or not it is of sufficient interest to merit more refined treatment. When a polished, literary translation is required, the product of an automatic dictionary should provide excellent raw material. Tedious, time-consuming reference to ordinary dictionaries could be eliminated; an editor presented with the original text and a translated version prepared by an automatic dictionary would be free to devote his attention to historical and literary context, to nuance, to style. A dictionary translation of the sample passage from Turgenev would include all ingredients necessary for the preparation of the four cited translations. It would remain only to select, combine, and season to taste.

The attention of a number of research groups is turned toward the realization of an automatic dictionary, which may be achieved in the not too distant future. The operation of an automatic dictionary would present a number of corollary advantages. In the normal course of operation vast quantities of text would be transcribed on punched cards, magnetic tape, or other automatically readable information storage media. The further development of automatic type readers may even make this transcription automatic. In any case, such texts would be useful in a variety of ways. Concordance making, on this basis, becomes an automatic process that can be completed economically in a matter of weeks, not lifetimes. Likewise, the compilation and revision of dictionaries can be greatly facilitated, since it should prove feasible to place at the disposal of the compiler large samples of contexts for any given word, from which he can determine the range of current usage, the relative frequency of various senses of the word, as well as sharper definitions of these senses in terms of their contexts. Statistical properties of texts of value to linguists, cryptographers, and students of information theory can be computed automatically. Large-scale studies of sentence structure, so essential for the continuing development of machine translation, become possible.

Syntactical Correspondence

It is evident that the automatic word dictionary assumes only a limited share of the burden of translation, one of a routine tedious nature and readily adaptable to simple automatic processes. Whether or not the burden of transcription from the printed page into machine language can also be assumed economically by automatic machines depends on the success of current technological developments. In the meantime, this task can be readily handled by monolingual clerical personnel trained, in the manner of telegraphists, to regard the source text as a coded message to be transmitted into the machine. The burden that remains taxes higher faculties in both men and machines.

It has been suggested earlier that processes analogous in spirit to those of arithmetic may prove useful in extending the power of dictionaries, and this possibility will now be considered. Since experiments indicate that automatic selection among alternative target correspondents of a single source word would be of greater value in improving the quality of dictionary output than other possible refinements, this question alone will be examined in detail.

Among the dictionary words with multiple correspondents, prepositions, conjunctions, and the like are the most troublesome. These are *function* words, carrying little meaning specific to a given text, but all-important in organizing the sentence, in establishing the relations between the other words, the *meaning* words. Meaning words include the nouns, verbs, adjectives, etc., which differentiate an English text on cooking, say, from one on chemistry. Such words may have one correspondent, like автоматический, or four or more, like перевод. Since the function words, although few in number, occur more frequently in texts than any comparable group of meaning words, they are responsible for a good share of the confusion introduced by multiple correspondents into a dictionary translation. The meaning words, however, are so numerous that, although each will occur far less frequently than any function word, as a class they seem to account for the majority of multiple correspondents in running texts.[25] Words with multiple correspondents belonging to different parts of speech create additional problems of their own.

Something like the problem of multiple correspondence exists even within a single language. For example, *Webster's New Collegiate Dictionary* lists eleven meanings of the word *for,* the specific interpretation depending, as always, on the context. Translation into a second language having a word precisely equivalent to *for* would present no difficulty, since the ambiguity in the translation would be no more nor less than that in the original. The problem, as Gould[25] puts it, arises from the fact that "in most Indo-European languages, prepositions are used in the expression of a large number of different concepts, and the combination of concepts embodied in a single preposition differs greatly from one language to another. Conversely, a single general concept is often expressed by a variety of prepositions, the appropriate choice of which must be considered idiomatic." The same might be said of many other classes of words.

One way of using context to narrow down the range of correspondents of a word is illustrated by a method developed in Russia for determining a unique correspondent of the word *of.* Figure 5[26] is what machine programers call a flow chart; it outlines a procedure for selecting among alternative Russian correspondents of *of,* and for generating case indicators for use in the translation of neighboring words. This procedure is similar to that represented in Fig. 2, and can be implemented by comparison and jump instruction of the type used in Fig. 1. The Russian experimenters used an English vocabulary of 952 words; their procedure apparently attempts to take account of all possible significant combinations of *of* with words in that vocabulary. The evident complexity of the procedure requires no comment; similar procedures have been prepared for other English prepositions. This approach, for the few function words which recur with high frequency, has considerable merit, but cannot be considered practical without further refinement. For instance, the simple phrase *the result of simple experiments* would defeat the procedure of Fig. 5. The sequence of decisions for this case is indicated by bold lines in Fig. 5; all goes well until box 21, where the wrong decision is made because of the interpolation of *simple* between *of* and *experiments.* The genitive indication is correctly developed, but *of* is translated от rather than not at all. This is not too serious an error, since the result

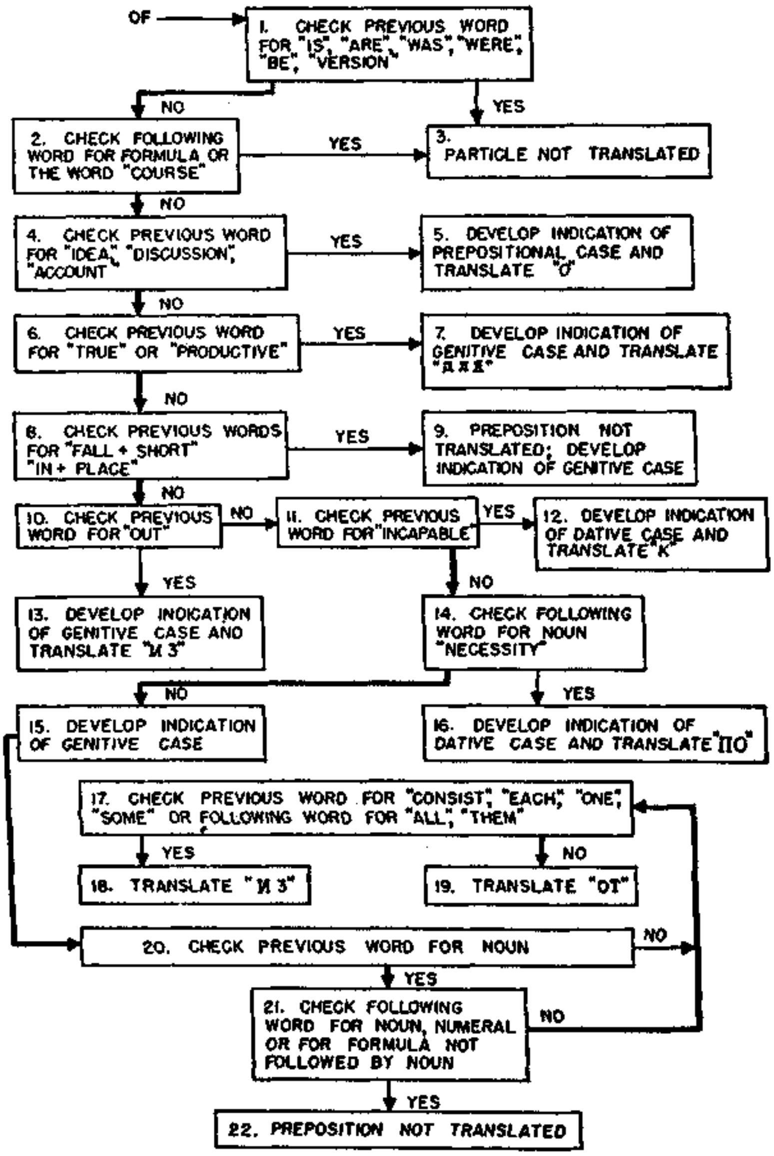

***Figure 5. Determination of Russian Correspondent of* of**

would probably be intelligible to a Russian. The title of the Russian paper, which presumably was not translated by machine, is a case in point. The Russians used *of,* where *in* would be more idiomatic, thereby giving the title a "translated" flavor, but in no way obscuring its meaning. If such mistakes are of no great consequence, the procedure of Fig. 5 may be too elaborate. The consistent use of only one of the alternative correspondents might lead to no more errors than the more complex procedure. On the other hand, the procedure of Fig. 5 could be altered so as to treat the example correctly, by adding *ad hoc,* to the conditions of box 21, a check for a noun preceded by an adjective as well as just for a noun.

The method of Fig. 5 relies on both the identification of specific contexts, e.g., "is the following word *course*?" and the identification of general contexts, e.g., "is the following word a noun?" The first type of identification is simple in principle, but must be limited in application to a few idiomatic constructions, since the number of words that can follow *of* is enormous. The second type of identification permits the use of one procedure for many specific contexts, provided that they can be recognized as belonging to the same class. For example, for the procedure in box 21 of Fig. 5 to be of general value, not only *experiments* and *simple experiments,* but *the experiments, extremely simple experiments, simple, well-designed, accurate experiments, observations, few observations,* etc., must be recognized as belonging to the same class of contexts of *of.* The example of arithmetic suggests a search for simple recursive rules for class identification, and the old-fashioned sentence diagram, now in disrepute, can give a clue as to how such rules may be obtained.

The sentences *Come here!* and *Go away!* of an earlier example may mean different things, but share the pattern *verb adverb!* with many other sentences. The sentence *John loves Mary* may be diagramed as it is in Fig. 6, a diagram characteristic of many sentences. In the sentence *the result invalidated the rule,* the same basic structure can be recognized if the sentence is analyzed as in Fig. 7, where the distinct words *the* and *result,* and *the* and *rule* are first grouped, and then the groups used to take the place occupied by nouns in the diagram of Fig. 6. The more complex sentence *the result of simple experiments invalidated the rule* may be diagramed as it is in Fig. 8. Although the structure of the sentence as a whole is complex, simpler structures recur within it, as, for example, *the result, the rule,* and *simple experiments;* and the whole system {[(the) result] [of (⟨sim-

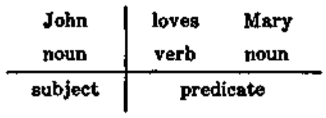

Figure 6.

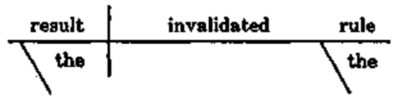

Figure 7.

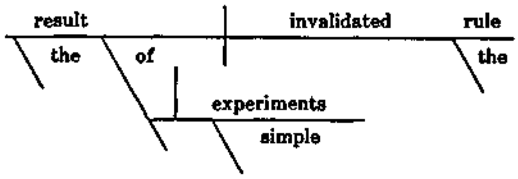

Figure 8.

ple⟩ experiments)]} in Fig. 8 plays the same role as *John* in Fig. 6. The same simple structures recur as components of other diagrams, each of which represents a vast number of possible sentences. It is possible then that a small number of rules applicable to these recurrent structures will therefore be valid for a much larger number of sentences. For example, it is the function of the test in box 21 of Fig. 5 to recognize the structure of *result of experiments,* whatever the particular nouns may be, and the test breaks down for *result of simple experiments* only because the recurrent pattern of *adjective modifying noun* has not been taken into account.

The sentence diagram as such cannot be used to identify patterns automatically. One reason for the current disrepute of this once popular teaching aid is that it places the cart before the horse. By some act of intuition, based on experience or on an answer in the back of the book, it has to be guessed that *the result of simple experiments* is the subject, and *invalidated the rule* the predicate. The predicate is then dismembered into the verb *invalidated* and the object *the rule,* where *the* modifies *rule,* and similarly for the subject. Such higher guessing is not possible for a machine. On the contrary, the division of a sentence into subject and predicate, which is the starting point of intuitive analysis, can only be the result of automatic analysis, which must be based on the morphology and on the order of the individual words in a sentence.

A sentence, as given to a machine, is simply a string of individual words. Something of the general pattern of the sentence may emerge if a part-of-speech or *word-class* designation is substituted for at least some words, as assumed in Fig. 5. For the automatic identification of a word with a word class, the class must be recognizable from the morphology of the word, as with nouns in *-ation,* or else the class designation must be stored with the dictionary entry for the word. Membership in a class can be established by the means outlined in the first section, and word classes are used to advantage in the flow chart of Fig. 5 for the definition of general contexts.

The next step, the recognition of patterns of word classes, is more difficult, but necessary for the generalization of procedures like that of box 21, Fig. 5. There are at present, to my knowledge, no methods for automatic word-class pattern analysis that have been tested on any but very limited vocabularies and sentence samples. One method, investigated by Salton,[27] attempts to make use of information supplied by punctuation to identify patterns. Yngve[28] has proposed a method based on the use of a dictionary of short word-class sequences, and illustrated its application with sentences formed from a 52-word vocabulary. These efforts, if successful, will significantly reduce the confusion due to multiple correspondents of function words. We can also expect a dent to be made in the problems of word order rearrangement, and of case, number, and similar indications, since the works of both Muxin and Yngve clearly indicate a close relationship between these unresolved questions and that of multiple correspondents of function words.

Selection among multiple correspondents of meaning words presents a somewhat different problem. While the significance of function words is deducible, at least partially, from their syntactical roles, that of meaning words depends not so much on syntax as on what the text is about. If different correspondents are marked, as they are in ordinary dictionaries, with notes such as *mathematical, nautical, colloquial,* etc., some selection is possible if the text is similarly marked before processing. If the text includes a sufficient number of unambiguous words related to a particular subject, automatic selection among multiple correspondents may be possible on the basis of internal consistency. Gould[25] has investigated this approach, but the evidence is insufficient to justify definitive conclusions.

Idioms create an interesting correspondence problem. In Bar-Hillel's words[28] "a given sentence in a language L_1 is *idiomatic with respect to a language* L_2, *to a given bilingual word dictionary from* L_1 *to* L_2, *and to a given list of grammatical rules* if, and only if, none of the sequences of the L_2 correspondents of the sequence of words of the given L_1 sentence is found to be grammatically and semantically a satisfactory translation, after perusal of the applicable grammatical rules." The italics are Bar-Hillel's, to emphasize the relative nature of idioms. An English expression idiomatic with respect to French may be straightforward with respect to German. An expression may be considered idiomatic if the words in it assume meanings different from those they have in other contexts, and hence whether or not it appears to be idiomatic depends on what senses of these words are given in the dictionary. Finally, what is an idiom with respect to a given set of syntactic rules may not be with respect to a more detailed set. Since idioms are often fossilized metaphors, special treatment may not be necessary if the metaphor is obvious in the target language, and since they are relatively rare in scientific writings, they have not proved seriously troublesome. Most writers conjecture that the extension of the word dictionary to include a small percentage of idiomatic phrases should be adequate to handle most occurrences. The phrases can be recognized by a process such as that indicated by box 2 of Fig. 5.

Any automatically operating machine may also automatically malfunction, and sound design must guard against this eventuality. The Westinghouse air brake is an outstanding early example of a device built in accordance with the *fail-safe* principle, which dictates that machines be built to act safely in the event of likely failures.

A minor mechanical failure that causes an automatic translator to misspell an occasional word is of no great consequence. Most texts are sufficiently redundant to remain quite intzlligiblz in spitz of somz garbling. Mechanical failures serious enough to cause complete garbling are annoying, but there is no danger of misinterpretation. Misinterpretation may arise, however, if the rules the machine is to obey when presented with a new word not listed in its dictionary, or with an unforeseen sentence pattern, are not made in accordance with the fail-safe principle.

New words can be handled relatively simply by transliteration. For cognates such as коммунист (kommunist) or алгебра (algebra) this course is highly satisfactory. For noncognates, e.g., напряжение (naprjazhenie) the transliteration may occur within the text in a number of contexts sufficient to define the meaning of the word. The strange transliteration warns the reader of the danger of misinterpretation and an ordinary dictionary may be consulted in doubtful cases.

Unforeseen sentence patterns present a more difficult problem. The consequences of failure are not easily ascertained. For example, the failure of the procedure of Fig. 5 with the phrase *of simple experiments* does not seem serious, but misinterpretation of more complex phrases is not ruled out. It can only be stated that an incoherent translation would be far less dangerous than a smooth translation that is wrong. It remains to work out methods for insuring that the translation of a sentence of unforeseen pattern will be either substantially correct, or else noticeably incoherent.

Enough has been said to indicate why the automatic translating machine, while not an idle dream, is not yet an operating reality. Meanwhile, the research continuing in many centers will deepen our understanding of the structure of languages and will, in time, lead to the operation of automatic machines whose purpose, in the words of Warren Weaver, is “not to charm or delight, not to contribute to elegance or beauty; but to be of wide service in the work-a-day task of making available the essential content of documents in languages which are foreign to the reader.”[30]

NOTES

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29. Y. Bar-Hillel, “Idioms,” Chapter 12 in Locke and Booth.

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